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(54) Dry process system.

(57) A dry process system comprises a chamber having an inlet of reaction gas and an exhaust port of exhaust gas, more than three electrodes connected with an alternating current power source through a blocking capacitor, respectively, and one or plural magnetic field applying means for generating magnetic field nearly parallel to a surface of each electrode. the distance between adjacent electrodes is set to an extent that electrons can travel nearly without collision in the space between adjacent electrodes. Since the distance between adjacent electrodes is narrow, one plasma generated at the neighborhood of one of the adjacent electrode and the other plasma generated at the neighborhood of the other electrode can commingle with each other so that distribution of plasma is made nearly uniform thus nearly uniform plasma can be formed without rotating magnetic field. Since the dry system is provided with electrodes of more than tree pieces,

multiple substrates can be effectively processed at the same time.

## DRY PROCESS SYSTEM

## BACKGROUND OF THE INVENTION

The present invention relates to a dry process system in which magnetron discharge is used and which can be used for CVD system, etching system, and sputtering system, and particularly to a dry process system comprising more than three electrodes which are arranged at regular intervals and parallel with each other, wherein magnetron discharge is generated between adjacent electrodes, respectively.

Fig. 1 is a schematic illustration of an example of conventional dry process system.

The conventional dry process system comprises a chamber 1, a cathode electrode 2 provided on the bottom of the chamber 1 with said electrode being insulated from the chamber 1 by an insulator 9. The cathode electrode 2 is connected through a blocking capacitor 7 with one terminal of high frequency power source or RF power source 6, while the other terminal of the high frequency power source and the chamber 1 are grounded. A pair of three-piece sets of solenoids 12 are provided outside the chamber 1 for generating magnetic field 11 in directions nearly parallel to the surface of the cathode electrode 2. Substrate or wafer 3 is disposed on the cathode electrode 2. Reaction gas 4 is introduced into the chamber 1 while exhaust gas 5 is discharged from the chamber 1. High frequency power  $P_h$  of 13.56 MHz is applied through the blocking capacitor 7 to the cathode electrode 2. The chamber 1 acts as an anode electrode 8. High frequency electric field 10 perpendicular to a surface of the cathode electrode 2 is generated over the cathode electrode 2, while magnetic field parallel to the surface of the cathode electrode 2 is generated by the solenoids.

Fig. 2 is a schematic illustration of another example of conventional dry etching system.

The conventional dry etching system has the same construction as the former conventional system except that an anode electrode 8 is opposed with a cathode electrode 2 at an interval of about 70 mm above the cathode electrode 2 in such a manner that the anode electrode 8 is parallel to the cathode electrode 2, and the anode electrode 8 is grounded.

These conventional systems operate as follows.

After substrate 3 to be etched is disposed on the cathode electrode 2, the chamber 1 is sufficiently evacuated by a vacuum pump and the reaction gas 4 is introduced into the chamber 1 to a gas pressure of about 10 mTorr. Thereafter high

frequency power  $P_h$  is supplied to the cathode electrode 2 from the high frequency power through the blocking capacitor 7, thereby the reaction gas is excited into plasma consisting of positive ions and negative electrons. By the supply of high frequency power into the cathode electrode, high frequency electric field 10 in a direction perpendicular to the surface of the cathode electrode 2 is generated.

Therewith, magnetic field 11 is generated in a direction parallel to the surface of the cathode electrode 2 by means of a pair of three-piece sets of solenoids. The high frequency electric field 10 and the magnetic field 11 intersecting each other formed in a space above the substrate causes spiral cycloidal motion of light electrons along an orbit of small radius and in a direction perpendicular to magnetic lines of force, said electrons being violently collided with neutral etching gas which results in generation of high density plasma, thereby magnetron discharge 13 being generated.

Since electrons existing in magnetic field are drifted in a direction perpendicular to the magnetic field by Lorenz forces, one-sided distribution of plasma densities is formed. To prevent this, a pair of three-piece sets of solenoids are arranged around the chamber 1, alternating current is passed in to the three-piece set of solenoids, thereby apparent rotating magnetic field is generated by which distribution of plasma density is apparently equalized.

Usually, ionization rate of reaction gas in the excitation of reaction gas due to, high frequency electric discharge is small, about  $10^{-4}$ . However since ionization rate in the magnetron discharge is higher than the former ionization rate by two digits,  $10^{-2}$ , therefore etching rate is made larger more than one digit due to magnetron discharge.

However in the above-mentioned systems, under static magnetic field, uniform etching is difficult, because one-sided distribution of plasma densities is formed. Variations of etching accuracy is high, and more than  $\pm 30\%$ . Further it is impossible to etch more than two substrates disposed on both the cathode electrode 2 and the anode electrode 8 at the same time, because self-bias voltage of the cathode electrode 2 is remarkably different from that of the anode electrode 8. Further it has been considered as being still more impossible to provide more than three electrodes in a chamber, dispose substrates on respective electrodes and etch the substrates at the same time and with good uniformity.

## SUMMARY OF THE INVENTION

Accordingly, it is one object of the present invention to provide a dry process system wherein multiple electrodes are arranged at regular intervals in a chamber and plural substrates disposed on respective electrodes can be processed at the same time and with good uniformity.

The above-mentioned object can be achieved by a dry process system which comprises a chamber having an inlet of reaction gas and an exhaust port of exhaust gas, more than three electrodes connected with an alternating current power source through a blocking capacitor, respectively, and one or plural magnetic field applying means for generating magnetic field nearly parallel to a surface of each electrode, and the distance between adjacent electrodes is set to an extent that electrons can travel nearly without collision in the space between the adjacent electrodes.

Further, the above-mentioned object of the present invention is also achieved by a dry process system which comprises a chamber having an inlet of reaction gas and an exhaust port of exhaust gas, more than three electrodes connected with an alternating current power source through a power distributing unit, respectively, and one or plural magnetic field applying means for generating magnetic field nearly parallel to a surface of each electrode, and the distance between adjacent electrodes is set to an extent that electrons can travel nearly without collision in the space between the adjacent electrodes.

Furthermore, the above-mentioned object of the present invention is also attained by a dry process system which comprises a chamber having an inlet of reaction gas and an exhaust port of exhaust gas, said chamber being connected with positive side of a direct current power source and grounded, more than three electrodes connected with negative side of the direct current power source, respectively, and one or plural magnetic field applying means for generating magnetic field nearly parallel to a surface of each electrode, and the distance between the adjacent electrodes is set to an extent that electrons can travel nearly without collision in the space between the adjacent electrodes.

In the present invention, the distance between adjacent electrodes is 1 to 5 cm, preferably 1 to 3 cm.

In the present invention, internal pressure of the chamber is about 1 to 100 mTorr, preferably 1 to 10 mTorr. Further, in the present invention, magnetic field is about 50 to 500 gauss.

In the present invention, it is preferable that the respective electrodes have equal areas to each

other, respectively, and the respective distances between adjacent electrodes are equal to each other.

In the present invention, when alternating current power source is used as a power source of the dry process system, the alternating current power source may be provided for supplying synchronously alternating current power having the same frequency to each electrode through the blocking capacitor under the appropriate phase difference.

Further, the alternating current power source can be provided for supplying synchronously alternating current power having the same frequency to each electrode through the blocking capacitor nearly under the same phase, wherein the chamber is grounded. In this case, the first group of electrodes and the second group of electrodes may be electrically connected with each other.

In the present invention, a set of a first alternating current power source and a second alternating current power source can be used as alternating current power source of the dry process system, wherein said first alternating current power source is connected with the second alternating current power source through a phase shifter.

In the present invention, the phase difference is in the region of  $0^\circ \pm 40^\circ$  or  $180^\circ \pm 40^\circ$ .

In the present invention, when gas for film forming such as SiH is used, the dry process system according to the present invention can be used as CVD (chemical vapor deposition) system. When etching gas such as CF is used, this system can be used as an etching system. Further when sputtering gas such as Ar is used, this system can be used as a sputtering system.

According to the present invention, magnetron discharge is generated, because the electric field and the magnetic field intersecting each other. This magnetron discharge generates plasma. A portion of light electrons existing in the plasma run into each electrode, which are stored in the blocking capacitor, thereby negative self-bias direct current voltage is formed.

With the formation of self-bias voltage, ion sheath having high positive ion concentration is formed in the neighborhood of each electrode. However, electric resistance of the ion sheath becomes high due to very low mobility of positive ions, thereby strong electric field is applied in the direction perpendicular to each electrode. The electric field corresponding to self-bias voltage formed in the ion sheath of each electrode runs against each electrode. Namely, the lines of the electric field corresponding to self-bias voltage formed in ion sheath of the first electrode is opposite in direction to the lines of the electric field corresponding to self-bias voltage formed in ion sheath of the second electrode opposed to the first

electrode. Because the magnetic fields are in the same direction and one electric field corresponding to the first electrodes and the other electric field corresponding to the second electrodes are in the opposite direction to each other, the direction of Lorenz force acting on the secondary electrons emitted from each electrode becomes, opposite to each other.

When the distance between adjacent electrodes is set to an extent that electrons can travel nearly without collision in the space between adjacent electrodes, one plasma generated at the neighborhood of one electrode and the other plasma generated at the neighborhood of the other electrode can commingle with each other so that distribution of plasma is made nearly equal. Accordingly nearly uniform plasma can be formed, without rotating magnetic field.

Further, when the distance between adjacent electrodes is set to an extent that electrons can travel nearly without collision in the space between the adjacent electrodes, because the ion sheath is formed on the surface of each electrode, electrons rotating about magnetic lines of force, when they run into the ion sheath, are repulsed by strong electric field of the ion sheath so that they are backed in the opposite direction. Accordingly, there is the high probability that the rotating electrons keep rotating until they collide with gas molecules without drifting largely right and left in the space. When the pressure of reaction gas corresponds to a pressure under which electrons can travel nearly without collision, electrons freely rotate by about one rotation before they collide with gas molecules. Gas pressure is inversely proportional to mean free path of electrons. Therefore, to make electrons rotate more than one rotation it is necessary to limit the gas pressure under the pressure under which electrons can travel nearly without collision.

Namely, when the distance between adjacent electrodes and pressure of reaction gas are those at which electrons can travel nearly without collision, electrons can keep drifting nearly right and left in the space between adjacent electrodes before electrons collide with gas molecules in the space so that plasma is generated. In other words, when the distance between adjacent electrodes is narrow, multiple electrons effectively run into the space between adjacent electrodes and effectively collide with gas molecules. Therefore plasma having higher density than usual magnetron plasma are generated. Further because drifts of electrons in right and left directions are low, plasma having good uniformity is generated.

Since ionization rate of plasma caused by magnetron discharge is higher by two digits or thereover than that of plasma caused by magnetron discharge, dry etching according to the

present invention can be performed at a higher rate of more than one digit as compared with the conventional system.

## BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

Fig. 1 is a schematic illustration of an example of a conventional dry etching system belonging to the category of dry process system;

Fig. 2 is a schematic illustration of another example of a conventional dry etching system belonging to the category of dry process system;

Fig. 3 is a schematic illustration of a first embodiment of dry process system according to the present invention;

Fig. 4 is a schematic illustration of a second embodiment of dry process system according to the present invention;

Fig. 5 is a schematic illustration of a third embodiment of dry process system according to the present invention;

Fig. 6 is a schematic illustration of a fourth embodiment of dry process system according to the present invention;

Fig. 7 is a schematic illustration of a fifth embodiment of dry process system according to the present invention;

Fig. 8(a) is a schematic representation of electron transport process model in plasma generated between electrodes opposed at a wide distance;

Fig. 8(b) is a schematic representation of electron transport process model in magnetron plasma generated between electrodes opposed at a narrow distance;

Fig. 9 is a graphical representation of emission spectrum of CHF magnetron plasma;

Fig. 10 is a graphical representation of gas pressure dependence of H $\alpha$  emission intensity;

Fig. 11 is a graphical representation of self-bias voltages(V) in the system according to the present invention and a conventional system to etching rate( $\mu$ m/min); and

Fig. 12 is a graphical representation of etch depth, distribution of 6-inch SiO wafer etched under rotating magnetic field.

## DETAILED DESCRIPTION OF THE INVENTION

The present invention is now explained by an example with reference to the drawings.

Fig. 3 is a schematic illustration of a first em-

bodiment of dry process system according to the present invention, in which the same reference characters as reference characters in Figs. 1 and 2 showing conventional systems designate like or corresponding parts as parts of the conventional systems shown in Figs. 1 and 2.

The first embodiment of the present invention comprises two first electrodes 21 and two second electrodes 22 which are arranged alternately and parallel to each other in the chamber 1. The first electrodes 21 are connected with one terminal of AC, or high frequency or RF power source 6 through a blocking capacitor 7 and the second electrodes 22 are connected with the other terminal of the high frequency power source 6 through a blocking capacitor 7. With a view to equalizing states of plasmas generated between adjacent electrodes 21, 22, it is preferable that the distances between adjacent electrodes should be of the same value, and areas of the respective electrodes are almost equal to each other so that capacitor of the blocking capacitor 7 for the first electrodes and capacitor of the blocking capacitor 7 for the second electrodes are almost equal to each other. A wire connecting the first electrodes 21 with one terminal of the high frequency power source 6 through the blocking capacitor 7 and a wire connecting the second electrodes 22 with the other terminal of the high frequency power source 6 through the blocking capacitor 7 are insulated from the chamber 1 by insulator 9, 9, respectively. A pair of three-piece sets of solenoids 12 are arranged outside the chamber 1 with surrounding the first and the second electrodes 21, 22 in an orientation such that magnetic field lines 11 are parallel to the first and the second electrodes 21, 22.

In the first embodiment, with a view to stabilizing plasma discharge one terminal of the high frequency power source is grounded. However, it is not always necessary to ground one terminal of the high frequency power source. When one terminal of the high frequency power source is not grounded, the chamber 1 is preferably grounded. When one terminal of the high frequency power source 6 is grounded, the chamber 1 is preferably in an electrically drifting state.

Further in the first embodiment, the dry process system is provided with one high frequency power source. However a two-unit set of high frequency power sources may be used which frequencies are synchronized at phase difference of 180 that is with opposite phase to each other so that the high frequency power sources are controlled to output the same power. When such a two-unit set of high frequency power sources are used, like operation and effect can be also obtained by supplying high frequency power to respective electrodes 21, 22 from the respective high

frequency power sources through respective blocking capacitors 7, 7. In this case, it is possible to change one electric energy which is supplied to the first electrodes and the other electric energy which is supplied to the second electrodes and change phase difference between power supplied to the first electrodes and power supplied to the second electrodes. Further it is possible to optimize distribution of plasma generated between both electrodes 21, 22 by suitably adjusting ratio of electric energy which is supplied to the first electrodes to electric energy which is supplied to the second electrodes and phase difference between power supplied to the first electrodes and power supplied to the second electrodes.

Further the solenoid 12 for applying magnetic field can be replaced by other means for applying magnetic field, for example combined rod-shaped permanent magnets. Any means for applying magnetic field 11 parallel to substrates 3 on the electrodes 21, 22 over the substrates can be used. Even under static magnetic field, enough uniformity of plasma densities can be obtained. However if the magnets are rotated, plasma densities are further leveled off so that uniformity of plasma densities is improved.

The substrates 3 are disposed on the electrodes 21, 22 respectively. However, it is not always necessary to arrange substrates 3 on both the electrodes 21, 22, but it is necessary only to dispose either the electrodes 21 or the electrodes 22. Since it is desirable that the first electrodes 21 and the second electrodes 22 are symmetric with respect to each other as much as possible, both the electrodes should be parallel to each other and ratio of area of the first electrodes 21 to that of the second electrodes 22 should be brought closer to 1 : 1 as much as possible. In this case, the blocking capacitor 7 for the first electrodes 21 and the blocking capacitor 7 for the second electrodes 22 preferably have the same capacity as much as possible.

In the first embodiment, the substrates 3 are disposed on the first electrodes 21 and the second electrodes 22. The chamber, 1 is sufficiently exhausted of the air by means of vacuum pump, add thereafter reaction gas 4 is introduced into the chamber 1 in such an extent that the internal pressure of the chamber 1 gets to about 1 to 100 mTorr or thereunder, thus the internal pressure of the chamber being adjusted. Electric current is sent through the solenoid 12, thereby magnetic field 11 of about 50 to 500 gauss being applied on the space between both the electrodes 21, 22 over the substrates 3 so that the magnetic field lines 11 run nearly parallel with each electrode 21, 22. Power Ph of the high frequency power source 6 is supplied through the blocking capacitors 7, 7 to the

first electrodes 21 and to the second electrodes 22 with opposite phase to each other. Electric field 10 is generated over the substrates 3 by the applied power Ph. Because the electric field 10 and the magnetic field 11 intersect at right angles, magnetron discharge is generated. Plasma is generated by the magnetron discharge, so that a part of light electrons in the plasma run into the first electrodes 21 and into the second electrodes 22, which are stored in the blocking capacitors 7 so that self-bias voltage is generated.

Ion sheaths in which positive ion density is higher in the neighborhood of the first electrodes 21 and the second electrodes 22 are generated with the generation of the self-bias voltage of negative direct current. Directions of the electric field lines 10 corresponding to self-bias voltage generated in the ion sheaths of the first electrodes 21 and the second electrodes 22 turn upward and downward, respectively. Because directions of magnetic field lines 11 are the same direction, and directions of the electric field lines 10 are opposite to each other, directions of Lorentz forces acting on secondary electrons emitted from each electrode 21, 22 are opposite to each other. Namely, in the neighborhood of the first electrodes 21, plasma density is higher at a region corresponding to the rear side of the paper on which figures are drawn (namely opposite side thereof), however it is lower at a region corresponding to the front side of the paper on which figures are drawn (this side). On the other hand in the neighborhood of the second electrodes 22, plasma density is lower at a region corresponding to the rear side of the paper on which figures are drawn (namely opposite side thereof), however it is higher at a region corresponding to the front side of the paper on which figures are drawn (this side).

When the distance between the first electrodes 21 and the second electrodes 22 is enough short so that the space between the first electrodes 21 and the second electrode 22 is set in such an extent that electrons can travel nearly without collision, one plasma generated in the neighborhood of the first electrodes 21 and the other plasma generated in the neighborhood of the second electrode 22 are mingled with each other without being separated from each other so that distribution of plasma densities is nearly uniform. Accordingly, plasma can be generated to be nearly uniform without rotating magnetic field. Of course the uniformity of plasma can be further improved if magnetic field is rotated. The distance between both the electrodes 21, 22 is preferably about 1 cm to 5 cm.

Ionization rate of plasma caused by the magnetron discharge is higher more than two digits as compared with ionization rate of plasma caused by the usual high frequency discharge. Therefore dry

etching can be performed by the first embodiment system at a high rate of more than one digit as compared with the conventional system.

In this system, when gas for film forming such as SiH is used, this system can be used as CVD (chemical vapor deposition) system. When etching gas such as CF is used, this system can be used as an etching system. Further when sputtering gas such as Ar is used, this system can be used as a sputtering system.

The system of the first embodiment enables six substrates 3 to be processed at the same time. Further it is possible to process substrates 3 of more than 12 pieces at the same time, by using this dry process system and disposing substrates 3 of more than 2 pieces on each electrode 21, 22. Further the total number of the first electrodes 21 and the total number of the second electrodes 22 may be more than 3 or 5, respectively, wherein it is necessary that the first electrodes 21 and the second electrodes 22 should be arranged alternately. As above-mentioned, the first electrodes 21 and the second electrodes 22 are preferably parallel to each other. However each electrode 21, 22 is not always of flat shapes, but may be of curved shape.

Fig. 4 is a schematic illustration of a second embodiment of dry process system according to the present invention, in which the same reference characters as reference characters in Fig. 3 designate the same as or corresponding parts to parts of the system as shown in Fig. 3.

The second embodiment comprises two first electrodes 21 and two second electrodes 22 which are electrically connected with each other so that the first electrodes 21 and the second electrodes 22 become equipotential to each other, and high frequency electric power Ph is synchronously supplied with equiphase to respective electrodes 21, 22 from the high frequency power source 6 through the blocking capacitor 7. The chamber 1 is grounded. The high frequency power source 6 can be replaced by a two-unit set of high frequency power sources which are synchronized with equiphase and controlled to have the same powers, thereby the similar operation and effect as in using one high frequency power source being obtained. In this case, electric energy and phase differences of powers supplied to the first and second electrodes from a two-unit set of high frequency power sources through the blocking capacitor can be different from each other. Therefore distribution of plasma generated between both the electrodes 21, 22 can be optimized by adjusting suitably the ratio of electric energy of power supplied to the first electrodes to electric energy of power supplied to the second electrodes and phase difference between power supplied to the first electrodes and power

supplied to the second electrodes. Further when one terminals of respective frequency power sources are grounded, the chamber is preferably grounded. The magnetic field 11 is applied parallel with each electrode 21, 22 by means of solenoid 12 as in the first embodiment. To improve plasma uniformity and generate plasma of high density, it is preferable to make the distance between the first electrode 21 and the second electrode 22 somewhat small, and about 1 cm to 5 cm. Such distance enables electrons to travel almost without collision in the space between the first electrode 21 and the second electrode 22. The first electrodes 21 and the second electrodes 22 can be also electrically connected with each other through conductive wire or conductive plate inside the chamber 1 so that the same effect as in the case where the first and second electrodes are electrically connected with each other outside the chamber.

In the first embodiment, the high frequency power source 6 is used as power source. However, in the present embodiment, the high frequency power source 6 can be replaced by direct power source. When direct current power source is used as power source, the blocking capacitor 7 is unnecessary. Negative voltage is directly applied to each electrode 21, 22, while positive voltage is directly applied to the chamber 1 or other electrode arranged inside the chamber. A substrate 3 or plural substrates 3 can be disposed on both electrodes 21, 22 or either electrode 21 or 22.

In the second embodiment, when gas for film forming such as SiH is used in the same manner as in the system of the first embodiment, this system can be used as CVD system. When etching gas such as CF is used, this system as Ar can be used as an etching system. Further when sputtering gas is used, this system can be used as a sputtering system. Further, conditions for generating plasma are almost the same as conditions given in the first embodiment.

In the second embodiment, electrodes more than 3 pieces can be used in the same manner as in the first embodiment, wherein it is preferable that respective electrodes 21, 22 are electrically connected with each other so as to become equipotential, areas of the respective electrodes are almost similar to each other, the respective distances between adjacent electrodes are almost similar to each other, and that the respective electrodes are parallel with each other. In this case, substrates more than 4 pieces can be disposed on opposed surfaces of adjacent electrodes.

In the first and second embodiments, the frequency power source is used as power source for generating plasma. However low frequency power source may be used as power source for generating plasma.

Fig. 5 is a schematic illustration of the third embodiment of dry process system according to the present invention, in which the same reference characters as reference characters in Figs. 2 showing a conventional system designate the same parts as or parts corresponding to parts of the conventional systems.

The third embodiment comprises two first electrodes 21 and two second electrodes 22 which are arranged alternately and parallel to each other in the chamber 1. In the third embodiment, as high frequency power sources for supplying independently high frequency electric powers Ph2, Ph1, the system is provided with high frequency power sources 26, 16. The first high frequency power 16 and the second high frequency power source 26 are connected through a phase shifter 17 with each other. A pair of high frequency power sources 26, 16 are controlled to oscillate with the same frequency at optional phase difference by means of a phase shifter 17. The high frequency electric powers Ph1, Ph2 can be independently controllable. The first electrodes 21 are connected with the one terminal of the second high frequency power source 26 while the second electrodes 22 are connected with one terminal of the first AC or high frequency power source 16. The other terminals of the respective high frequency power sources are grounded. To equalize conditions of plasma generated in each space between the adjacent electrodes, it is preferable that respective distances between adjacent electrodes are equal to each other, areas of respective electrodes 21, 22 are almost equal to each other, and that the capacities of blocking capacitors 7, 7 for first electrodes and the second electrodes are almost equal to each other.

Further the solenoid 12 can be replaced by the other means for applying magnetic field between adjacent electrodes, for example rod-shaped permanent magnetics which are combined into one. Any means for applying magnetic field 11 nearly parallel to substrates 3 on the electrodes 21, 22 can be used. Even under static magnetic field, enough uniformity of plasma densities can be obtained. However if the magnetic field is rotated, plasma densities are further leveled off so that uniformity of plasma densities are improved.

In the third embodiment, the substrates 3 are disposed on the electrodes 21, 22, respectively. The chamber 1 is sufficiently evacuated, and thereafter reaction gas 4 is introduced into the chamber 1 in such an extent that, the internal pressure of the chamber get to about 1 to 100 mTorr or thereunder. Electric current is sent through the solenoid 12, thereby magnetic field 11 of about 50 to 500 gauss being applied on the space between adjacent electrodes 21, 22 so that the magnetic field



lines run nearly parallel with, each electrode 21, 22.

Electric powers Ph1, Ph2 of the high frequency power sources 16, 26 are supplied to the respective electrodes 21, 22 at arbitrary phase difference and arbitrary power supply ratio through the blocking capacitor 7, and electric field is generated over the substrates 3 by applied powers Ph1, Ph2. The direction of the electric field changes according to the phase difference and power supply ratio of the powers Ph1, Ph2. Because the electric field 10 and the magnetic field 11 intersect at right angles, magnetron discharge is generated. Plasma is generated by the magnetron discharge, so that a part of light electrons in the plasma run into the first electrodes 21 and into the second electrodes 22, which is stored in the blocking capacitors 7 so that negative self-bias voltage is generated. Ion sheaths in which positive ion densities are higher are generated in the neighborhood of the first electrodes 21 and the second electrodes 22 with the generation of the negative self-bias voltage. In the ion sheath section, there are positive ions having high densities. However, since the mobility of positive ion is remarkably low, electric resistance of ion sheath section becomes higher so that strong electric fields are applied in the direction perpendicular to the respective electrodes 21, 22. The directions of electric fields corresponding to the self-bias voltage generated in the ion sheath sections of the first and second electrodes 21, 22 point toward the respective electrodes 21, 22, namely turn upward and downward, respectively which are in opposite direction to each other. By electric fields, positive ions are accelerated, accelerated positive ions are collided against the first and second electrodes 21, 22 while secondary electrons are emitted.

In such conditions, when the distance between adjacent electrodes 21, 22 is changed, the following difference between a case where the distance between adjacent electrodes is wider and a case where the distance between both the electrodes is narrow.

This system enables six substrates 3 to be processed at the same time. Further it is possible to process substrates 3 more than 12 pieces at the same time, by using this dry process system and disposing substrates 3 more than 2 pieces on each electrodes 21, 22. Further the total number of the electrodes 21 and the total number of the electrodes 22 may be more than 3 or 5, respectively, wherein the first electrodes 21 and the second electrodes 22 should be arranged alternately. The first electrodes 21 and the second electrodes 22 are preferably parallel to each other. However each electrode 21, 22 is not always of flat shape, but may be of curved shape.

Fig. 8 (a) shows motions of electrons in plasma when the distance between the first and second

electrodes 21, 22 is wider, for example about 60 mm to 100 mm. Because the distance between adjacent electrodes is enough wide, secondary electrons emitted from the respective electrodes 21, 22 are drifted right and left by the action of electric field and magnetic field which intersect at right angles. Such a motion is referred to as cycloid motion. Because secondary electrons emitted from the first electrode 21 are drifted right whereas secondary electrons emitted from the second electrode 22 are drifted left, the uniformity of plasma is comparatively good in the central zone between both the electrodes 21, 22.

However, electrons moving in right and left directions are accumulated on both ends of the space between both the electrodes, plasma densities at both ends of the space between are remarkably higher, therefore etching or CVD uniformity is bad.

On the other hand, in the third embodiment of the present invention, secondary electrons emitted from the first and second electrodes 21, 22 move along tracks as shown in Fig. 8(b) which shows motions of electrons in plasma when the distance between adjacent electrodes is narrow, about 10 mm to 30 mm. Now, supposing that magnetic flux density of magnetic field and self-bias voltage are 150 gauss and 200 V, respectively, radius of gyration of electron, that is Larmors radius is about 4mm. Therefore diameter of rotary motion of a secondary electron about magnetic line of force is about 8 mm. There is a high probability that secondary electrons rotating about magnetic lines of force with drawing a circle of diameter about 8 mm approach the opposite electrodes. Because an ion sheath is formed on the surface of electrode, electrons are repulsed by strong negative electric field, and returned in the opposite direction. Therefore when the distance between adjacent electrodes is narrow, there is a high probability that electrons continue rotating without largely drifting right and left until rotating electrons collide with gas molecules.

Namely, in the Fig. 8(b) embodiment, since the distance between adjacent electrodes is narrow, about 10 mm to 30 mm, electrons can move in gas having pressure of about 1 Pa (7.5 mTorr) without collision covering about 50 mm, therefore, said electrons travelling without collision in the space between adjacent electrodes. By the way the distance in which electrons in gas molecules can freely move until electrons in gas molecules collide with gas molecules is called mean free path. the circumference of a circle of diameter about 8 mm is about 25 mm. Gas pressure under which the length of mean free path extends to 25 mm is about 10 mTorr, although it somewhat differs depending on sorts of gas. Accordingly in a gas



having pressure of 10 mTorr, electrons freely rotate covering about one rotation under the above-mentioned plasma generation conditions so that electrons collide with gas molecules. Since the length of mean free path of electron is inversely proportional to gas pressure, it is necessary to keep under about 10 mTorr in such a manner that electron is enabled to rotate over one rotation. Namely, in case that the distance between adjacent electrodes is about 10 to 30 mm, when gas pressure is under about 10 mTorr, electrons continue rotating in the space between adjacent electrodes 21, 22 nearly without drifting right and left, and collide with gas molecules so that plasma consisting of ions or radicals is generated.

When the distance between adjacent electrodes is narrow, about 10 to 30 mm, plasma having higher densities than densities of usual magnetron plasma is generated, because multiple electrons are emitted into the narrow space between adjacent electrodes and effectively collide with gas molecules. In this manner, since generated plasma densities are higher, electric field applied in plasma is weak, and drifting of electrons toward right and left direction is small. Namely because drifting of electrons in right and left directions in Fig. 8(b) differing from Fig. 8(a), electrons emitted from the respective electrodes 21, 22 continue rotating about magnetic lines of force in the space between adjacent electrodes 21, 22, and effectively collide with gas molecules so that plasma having good uniformity is generated, whereas in Fig. 8(a), collisions of electrons emitted from the respective electrodes 21, 22 with gas molecules are few so that in this case plasma densities is not very so increased as compared with the density of usual magnetron plasma. However as shown in Fig. 8(b), plasma densities can be still more increased differing from usual magnetron plasma, by setting the distance between adjacent electrodes 21, 22 at 10 to 30 mm, that is at value within four times of about 8 mm of diameter of a circle of rotary motion, and by lowering gas pressure to under about 10 mTorr. Thereby, since plasma generated about the first electrode 21 and plasma generated about the second electrode 22 are mixed together without separating from each other, uniformity of distribution of plasma densities can be increased. Further since plasma is effectively generated in the narrow space by electrons emitted from the first and second electrodes 21, 22, high density plasma having plasma densities higher by two times as compared with usual magnetron plasma can be generated. Accordingly uniform high density plasma can be generated, without rotating magnetic field. The uniformity of plasma can be still more improved by rotating magnetic field.

Fig. 9 shows emission spectrum of CHF gas at

pressure 1 Pa obtained by means of the system according to the third embodiment, wherein bright-line spectrum of wave length 656.3 nm is  $\alpha$ -ray spectrum ( $H\alpha$ ). The intensity of  $H\alpha$ -rays shows light intensity of hydrogen atom generated by decomposition of CHF, and an extent of decomposition of CHF, that is plasma density. Fortunately, as noise light in the neighborhood of  $H\alpha$ -rays is little, the comparison of plasma densities can be achieved by the comparison of  $H\alpha$ -ray intensities.

Fig. 10 shows gas pressure dependence of  $H\alpha$ -emission intensity when CHF gas is introduced into the system according to the third embodiment, and gas pressures thereof are changed from 0.4 to 10 Pa. As shown in Fig. 10, even if gas pressure is lowered from 10 Pa to 0.4 Pa,  $H\alpha$  emission intensity is almost unchanged. Although such lowering of gas pressure from 10 Pa to 0.4 Pa corresponds to weaken the inside of the chamber by 40 times in terms of gas molecule density, densities of emitting plasma are unchanged. Namely, efficiencies of plasma generation are increased as gas pressure is lowered under about 1 Pa.

There are following relations between phase difference between power Ph2 and power Ph1 and uniformities of plasma. At phase differences within the range of  $0 \pm 40^\circ$  from  $0^\circ$ , plasma uniformities are fairly good, to the extent that plasma can be visually observed to be nearly uniform. In such plasma conditions and under static magnetic field 11, good etching uniformity of about  $\pm 15\%$  can be obtained. On the contrary, in said plasma conditions and under rotating magnetic field 11, fairly good etching uniformities of about  $\pm 3\%$  can be obtained.

Then, when phase differences are set within the range of about  $180 \pm 40^\circ$ , plasma uniformity is somewhat lowered as compared with the plasma uniformities at phase differences in the range of about  $180 \pm 40^\circ$  to the extent that plasma having somewhat strong light emissions are visible at both ends of the space between the first and second electrodes 21, 22, which both ends are aligned with the directions perpendicular to magnetic lines of force 11. The substrates 3 in the neighborhood of the plasma having strong light emission are etched at a somewhat higher etching rate as compared with etching rate of the other region of the substrates, so etching uniformities over whole region of the substrates are worse than the case at phase differences in the range of  $0 \pm 40^\circ$ . In such conditions and under static magnetic field 11, etching uniformities of about  $\pm 30\%$  can be obtained. In the same plasma conditions and under rotating magnetic field 11, fairly good etching uniformities of about  $\pm 3\%$  can be obtained. In the range of phase difference except the above-mentioned ranges of phase difference, intermediate un-

iformities which lies in the region between the uniformities obtained at phase differences which lies in the neighborhood of 0° and the uniformities obtained at phase difference which lies in the neighborhood of 180

There is not the very close relation between plasma density and phase difference. In any phase difference, stronger plasma than usual magnetron plasma is generated. Accordingly in any phase, the substrates can be etched at a higher rate than in usual magnetron plasma. When insulate dielectric plate is inserted between the first electrode 21 or the second electrode 22 and the substrate 3 disposed on the first electrode 21 or the second electrode 22, there is a case that phase difference between high frequency power at the first electrode 21 or the second electrode 22 and high frequency power at the substrates 3 is generated. In this case, it is preferable that the phase difference between high frequency powers Ph 1 and Ph 2 is defined and considered as phase difference between high frequency power Ph 1 applied on the substrate 3 and high frequency power Ph 2 applied on the substrate 3.

Plasma uniformities are delicately influenced by high frequency power supply ratio of the power Ph 2 supplied to the first electrodes 21 to the power Ph 1 supplied to the second electrodes 22. When power supplied to either electrodes 21 or 22 or powers supplied to both the electrodes 21 and 22 are enough high, strong plasma is generated. In this case, when either the first electrodes or the second electrodes are grounded or when power is not supplied to either the first electrodes or the second electrodes, extremely not uniform plasma is generated and plasma densities are fairly decreased. For example, when the power Ph 2 supplied to the first electrodes 21 is sufficiently high while the power Ph 1 supplied to the second electrodes 22 is somewhat lower, high density plasma is generated in the space between the first and second electrodes 21 and 22. Self-bias voltage at the first electrodes 21 becomes high, ion sheath becomes thicker and kinetic energy of positive ion incident on the substrate 3 becomes high. On the contrary, self-bias voltage of the second electrodes 22 becomes lower, ion sheath becomes thinner and kinetic energy of positive ion incident on the substrate 3 becomes lower. Therefore such system is suitably used for etching the substrates 3 or sputtering at a high rate with high ion energy, while the second electrodes 22 can be used suitably for etching or plasma processing and as CVD with small amount of ion energy, at a somewhat high rate and with small loss of ion by collision.

When the power Ph 2 supplied to the first electrodes 21 and the power Ph 1 supplied to the second electrodes 22 are equalized with each

Other, the system can be suitably used for performing etching or plasma processing such as CVD the substrates 3 on the first and second electrodes 21 and 22 or plasma processing such as CVD under the almost same conditions. Therefore when the ratio of the power supplied to either of the first electrodes 21 or the second electrodes 22 to total power supplied to the first and second electrodes 21 and 22 is about 20 to 80%, strong higher density plasma can be generated as compared with usual magnetron plasma.

When the distance between adjacent electrodes 21 and 22 is sufficiently narrow to the extent that electrons can move in the space between the first and second electrodes 21 and 22 and turning about magnetic lines of force almost without collision, electrons emitted from the first and second electrodes 21 and 22 can continue rotating with being moderately mixed in the space between the first and second electrodes 21 and 22. Therefore plasma having higher density than that of usual magnetron plasma is generated to be almost uniform. Accordingly almost uniform plasma can be obtained under static magnetic field. Of course, if magnetic field is rotated, plasma uniformity is further improved.

Ionization rate of plasma caused by magnetron discharge is higher more than two digits as compared with ionization rate of plasma caused by usual high frequency discharge. Therefore dry etching can be performed by the third embodiment system at a high rate of more than one digit as compared with the conventional system.

In the system, when gas for film forming such as SiH is used, this system can be used as CVD system. When etching gas such as CF is used, this system can be used as an etching system. Further when sputtering gas such as Ar, this system can be used as a sputtering system.

Fig. 6 is a schematic illustration of a fourth embodiment of dry process system according to the present invention, in which the same reference characters as reference characters shown in Fig. 5 designate the same parts or corresponding parts to parts shown in Fig. 5.

The fourth embodiment comprises two first electrodes 21 and two second electrodes which are arranged alternately and parallel to each other in the chamber 1 grounded. The first and second electrodes are through a power distributor 27 with the high frequency power source 6

The other terminal of the high frequency power source 6 is grounded. To equalize conditions of plasma generated in each space between adjacent electrodes, it is preferable that respective distances between adjacent electrodes are equal to each other and areas of respective electrodes 21, 22 are almost equal to each other, and that the blocking

capacitors incorporated in the output units of the power distributor for the first electrodes and the second electrodes are equal to each others,

The power distributor 27 has a transformer for distribution of power of one-input-to-two-output type, a phase control unit including a coil and a variable condenser, and a matching box for matching impedance of the first electrode to impedance of the second electrode. The matching box incorporates a blocking capacitor at output units thereof. There are some combinations of the number of the transformers for distribution of power, the phase control units and the matching box, a method for connecting them and connecting the order of connected them. However it is considered that any units which can optionally control the ratio of powers and phase difference for one input are coordinate with the above-mentioned power distributor. In the output distributor, all of the transformer for distribution of power, the phase control unit, the matching box are not always necessary. Like effect can be obtained for example by simply branching output from a matching box into two outputs. In this case, control of distribution rate and phase difference is not easy and optimizing conditions of plasma generation is not easy, but this system is suitable for low cost system which is comparatively simple and is composed of few parts.

The power distributor 27 branches high frequency power Ph of the high frequency power source 6 into first and second powers Ph1 and Ph2 having optional ratio of powers and phase difference, respectively, which can be supplied to the second electrode 22 and the first electrode 21. In such a manner, the same action by one high frequency power source 6 as the case in which two high frequency powers 16 and 26 are used is possible.

A use, operating procedure and operating state are almost the same as them of the dry process system in Fig. 5.

In the third and the fourth embodiments, the high frequency power source is used as power source for generating plasma. However high frequency power source can be replaced by low frequency power source.

Fig. 7 is an illustration of a fifth embodiment of the present invention, in which the same reference characters as reference characters in Fig. 5 designate the same parts as or corresponding parts to parts of the system shown in Fig. 5.

The fifth embodiment comprises two first electrodes 21 and two second electrodes 22 which are arranged alternately and parallel to each other in the chamber 1. The first electrodes 21 are connected with negative terminal of the second DC power source 25 while the second electrodes 22 are connected with negative terminal of the first DC

power source 15. Positive terminals of the DC power source 15, 25 are connected with the chamber 1 or grounded. When the DC power sources are grounded, the chamber 1 is also grounded. To optionally control power supplied to the first electrodes 21 and power supplied to the second electrodes 22, output voltage of each DC power source 25, 15 should be optionally controllable. To control optionally power supplied to the first electrodes 21 and power supplied to the second electrodes 22, in the fifth embodiment, two DC power sources are used. However by dividing output from one DC power source into two by means of a potential divider to supply power to the first and second electrodes 21, 22, the same action of the system is possible.

To equalize conditions of plasma generated in each space between the adjacent electrodes, it is preferable that respective distances between adjacent electrodes 21, 22 are almost equal to each other, and that area of each electrode 21, 22 is almost equal to each other.

In the fifth embodiment, when gas for film forming such as SiH is used, the system can be used as CVD system. When etching gas such as CF is used, the system can be used as an etching system. Further when sputtering gas such as Ar, the system can be used as a sputtering system. Further conditions for generating plasma are almost the same as them shown in the third and fourth embodiments.

Further in the third through the fifth embodiments, it is preferable that gas pressure is under about 1 Pa and the distance between the first and second electrode 21, 22 is about 10 mm to 30 mm. However if gas pressure is lowered and mean free path is lengthened, the distance between the first and second electrodes 21, 22 may be wider. It is advisable that gas pressure is considered as being inversely proportional to the distance between electrodes to determine gas pressure and the distance between adjacent electrodes. Further since the distance between the first and second electrodes 21, 22 have relation to the diameter of rotation of electron, when the distance between adjacent electrodes is made narrow, it is necessary to decrease the diameter of rotation of electron by that the more the distance between electrodes is decreased, the more magnetic field intensity is increased, while when the distance between electrodes is made wider, it is necessary to increase the diameter of rotation of electron by that the more the distance between electrodes is increased, the more magnetic field intensity is decreased. Magnetic field intensity is considered as being generally inversely proportional to the diameter of rotation of electron. Accordingly, it is advisable that magnetic field intensity is inversely proportional to

the distance between the first and second electrodes and proportional to gas pressure. It is preferable that magnetic field of about 150 to 200 gauss is applied, when gas pressure is about 1 Pa and the distance between adjacent electrodes is about 10 to 30 mm.

Fig. 11 is a graphical representation of self-bias voltage dependence of etching rate when photo resist is etched by O plasma.

In Fig. 11, line a shows etching rates of photo resist by means of the dry process systems of the third through the fifth embodiments according to the present invention depending on self-bias voltage and line b shows etching rate of photo resist by the conventional magnetron etching system. At self-bias voltage 35 V, etching rate of photo resist by means of the third through the fifth embodiments is higher by about two times than etching rate of photo resist by conventional magnetron etching system. At self-bias voltage over 35 V, etching rate of photo resist by means of the third through fifth embodiments is also higher by about forty percent than etching rate of photo resist by conventional magnetron etching system. This difference of etching rate means difference of plasma densities. It means that the dry process etching system of the third through the fifth embodiments according to the invention can produce plasma having higher densities as compared with the conventional magnetron etching system.

The dry process systems of the third through the fifth embodiments can produce high density plasma with fairly good uniformity, because secondary electron emitted from each electrode 21, 22 is rotated by the action of magnetic field 11 in the space between the first and second electrodes and shut within said space. This plasma uniformities are by far superior to usual magnetron plasma. This plasma uniformity can be further improved by rotating magnetic field 11 so that magnetic field intensities are equalized. The plasma uniformity can be determined by etching the substrates 3. Under static magnetic field, when etching is carried out by usual magnetron plasma, variations in etching rate are  $\pm 35\%$ , therefore the substrates are not processed so as to close tolerance. On the contrary, under static magnetic field, when etching is carried out by means of the dry process systems of the third through fifth embodiments according to the present invention, variations in etching rate are  $\pm 15\%$ , therefore the substrates can be processed to fairly close tolerance. Further under rotary magnetic field, plasma uniformity is further improved in such an extent that excellent etching uniformity of  $\pm 3\%$  can be obtained used by using the dry process systems of the third through the ninth embodiments according to the present invention.

Fig. 12 is a graphical representation of etch

depth distributions of 6 inch SiO substrate etched with introducing CHF gas into the dry process systems of the third through the fifth embodiments of the present inventions, wherein etching time is about one minute and magnetic field is rotated. Since magnetic field is rotated, variations in etching accuracy are distributed almost symmetrically with respect to the central axis within the substrates. The etching uniformity is about  $\pm 4\%$ . Thus, the dry process system of the third through the fifth according to the present invention can be produce more uniform magnetron plasma as compared with conventional dry process system.

Since gas pressure at which magnetron discharge is obtained is fairly low, under above 1 Pa (7.5 mTorr) very directional etching is possible, and it is possible to produce a thin film with high quality and including a small quantity of impurities. Further since plasmas having almost the same conditions can be obtained in the neighborhood of the first and the second electrodes 21, 22, more than two substrates 3 disposed on the respective electrodes 21, 22 can be processed at the same time.

Further since magnetic field is applied almost parallel with the substrates 3, electrons in plasma are difficult to flow toward the substrates, so ion sheath is hard to be formed. Therefore since self-bias voltage is decreased to less than 115 of that in conventional dry process system so that damage caused by ions incident on the substrates are decreased. For this reason, the dry process systems of the third through fifth embodiments according to the present invention are suitable particularly for etching with low rate of damage generation, vapor deposition of material for gate, trench etching or lead. Further according to the present invention, miniaturization of dry process system becomes possible.

## Claims

(1) A dry process system which comprises a chamber having an inlet of reaction gas and an exhaust port of exhaust gas, more than three electrodes connected with an alternating current power source through a blocking capacitor, respectively, and one or plural magnetic field applying means for generating magnetic field nearly parallel to a surface of each electrode, and the distance between adjacent electrodes is set to an extent that electrons can travel nearly without collision in the space between adjacent electrodes.

(2) A dry process system as claimed in claim 1, wherein said alternating current power source supplies synchronously alternating current power having the same frequency to each electrode through the blocking capacitor under the appropriate phase

difference.

(3) A dry process system as claimed in claim 1, wherein the first group of electrodes and the second group of electrodes are electrically connected with each other.

(4) A dry process system as claimed in claim 13 wherein said alternating current power source supplies synchronously alternating current power having the same frequency to each electrode through the blocking capacitor nearly under the same phase, and the chamber is grounded.

(5) A dry process system as claimed in claim 13 wherein the distance between adjacent electrodes is 1 to 5 cm.

(6) A dry process system as claimed in claim 1, wherein the chamber is evacuated to a pressure of about, 1 to 100 mTorr or thereunder, electric current is passed through the magnetic field applying means in such an extent that magnetic field of about 50 to 500 gauss is generated.

(7) A dry process system as claimed in claim 1, wherein the distance between adjacent electrodes is 10 to 30 mm, and a pressure inside the chamber is under about 10 mTorr.

(8) A dry process system as claimed in claim 1, wherein said alternating current power source comprises a set of a first alternating current power source and a second alternating current power source, said dry process system further comprises a phase shifter inserted between the first alternating current power source and the second alternating current power source, the first group of electrodes are connected with the first alternating current power source through the first blocking capacitor and the second group of electrodes are connected with the second alternating current power source through the second blocking capacitor.

(9) A dry process system as claimed in claim 2, wherein said phase difference is in the region of  $0^\circ \pm 40^\circ$ .

(10) A dry process system as claimed in claim 2, wherein said phase difference is in the region of  $180^\circ \pm 40^\circ$ .

(11) A dry process system as claimed in claim 1, wherein the respective electrodes have areas equal to each other, respectively, and the respective distances between adjacent electrodes are equal to each other.

(12) A dry process system which comprises a chamber having an inlet of reaction gas and an exhaust port of exhaust gas, more than three electrodes connected with an alternating current power source through a power distributing unit, respectively, and one or plural magnetic field applying means for generating magnetic field nearly parallel to a surface of each electrode, and the distance between adjacent electrodes is set to an extent that electrons can travel nearly without collision in the

space between adjacent electrodes.

(13) A dry process system as claimed in claim 12, wherein said alternating current power source supplies synchronously alternating current power having the same frequency to each electrode through the power distribution unit under the appropriate phase difference.

(14) A dry process system as claimed in claim 12, wherein said alternating current power source supplies synchronously alternating current power having the same frequency to each electrode through the power distribution unit nearly under the same phase, and the chamber is grounded.

(15) A dry process system as claimed in claim 12, wherein the distance between adjacent electrodes is 1 to 5 cm.

(16) A dry process system as claimed in claim 123 wherein the chamber is evacuated to a pressure of about 1, to 100 mTorr or thereunder, electric current is passed through the magnetic field applying means in such an extent that magnetic field of about 50 to 500 gauss is generated.

(17) A dry process system as claimed in claim 12, wherein the distance between adjacent electrodes is 10 to 30 mm, and a pressure inside the chamber is under about 10 mTorr.

(18) A dry process system as claimed in claim 13, wherein said phase difference is in the region of  $0^\circ \pm 40^\circ$ .

(19) A dry process system as claimed in claim 13, wherein said phase difference is in the region of  $180^\circ \pm 40^\circ$ .

(20) A dry process system as claimed in claim 12, wherein the respective electrodes have areas equal to each other, respectively, and the respective distances between adjacent electrodes are equal to each other.

(21) A dry process system which comprises a chamber having an inlet of reaction gas and an exhaust port of exhaust gas, said chamber being connected with positive side of a direct current power source and grounded, more than three electrodes connected with negative side of a direct current power source, respectively, and one or plural magnetic field applying means for generating magnetic field nearly parallel to a surface of each electrode, and the distance between adjacent electrodes is set to an extent that electrons can travel nearly without collision in the space between adjacent electrodes.

(22) A dry process system as claimed in claim 21, wherein the distance between adjacent electrodes is 1 to 5 cm.

(23) A dry process system as claimed in claim 21, wherein the chamber is evacuated to a pressure of about 1 to 100 mTorr or thereunder, electric current is passed through the magnetic field applying means in such an extent that magnetic field of

about 50 to 500 gauss is generated.

(24) A dry process system as claimed in claim 21, wherein the distance between adjacent electrodes is 10 to 30 mm, and a pressure inside the chamber is under about 10 mTorr.

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(25) A dry process system as claimed in claim 23, wherein the respective electrodes have areas equal to each other, respectively, and the respective distances between adjacent electrodes are equal to each other.

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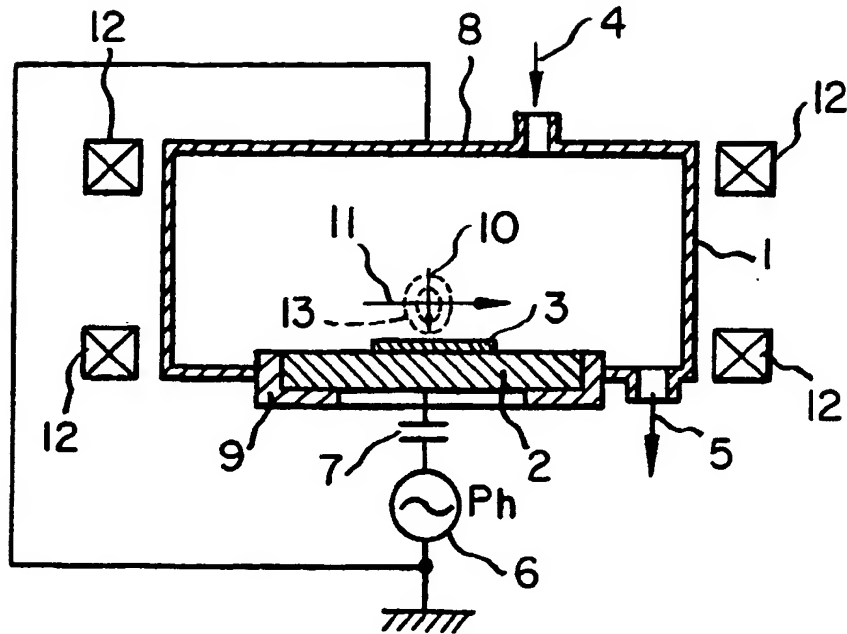
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**FIG. 1** **PRIOR ART**



**FIG. 2** **PRIOR ART**

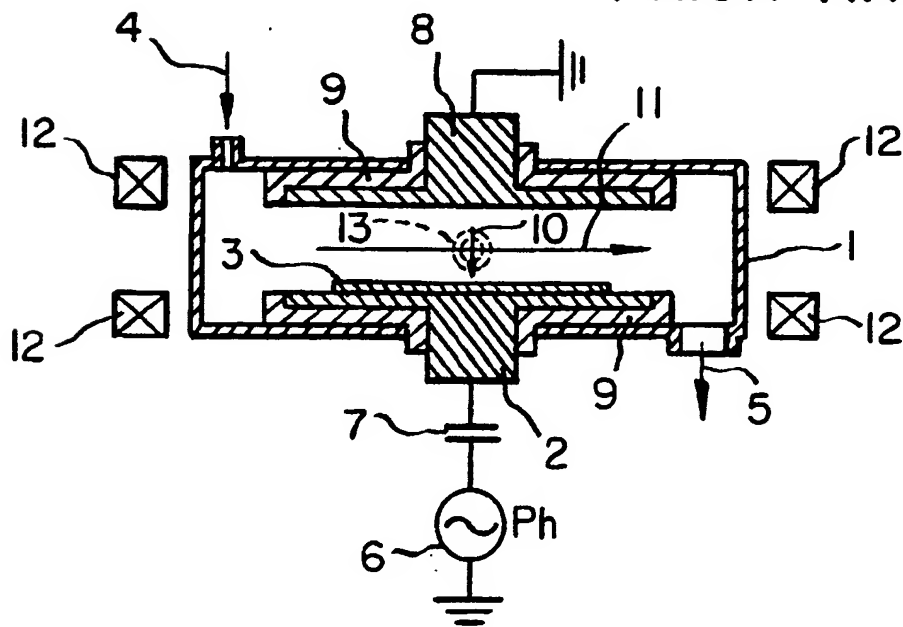




FIG. 3

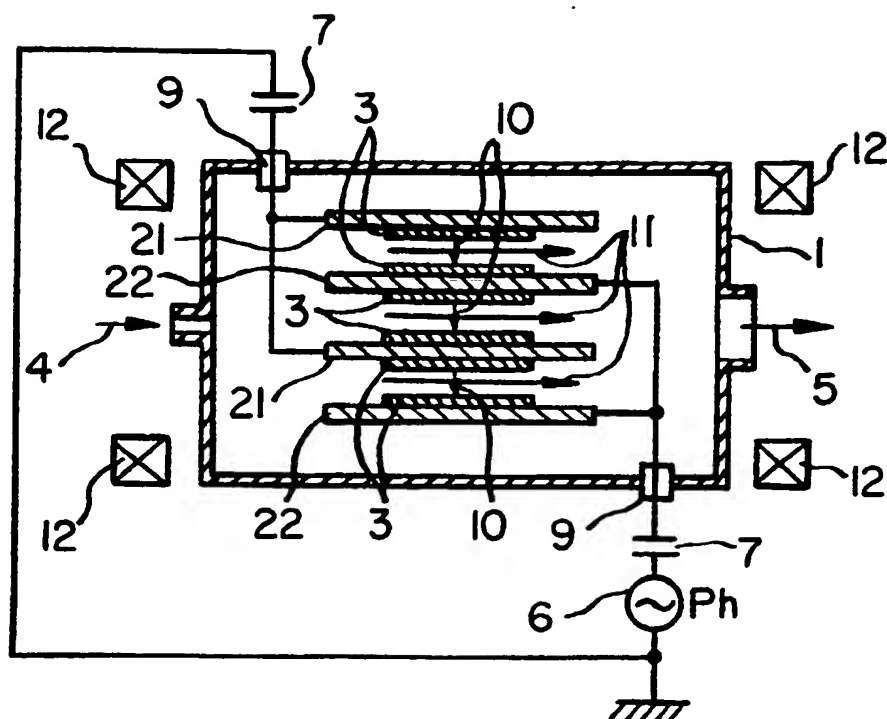


FIG. 4

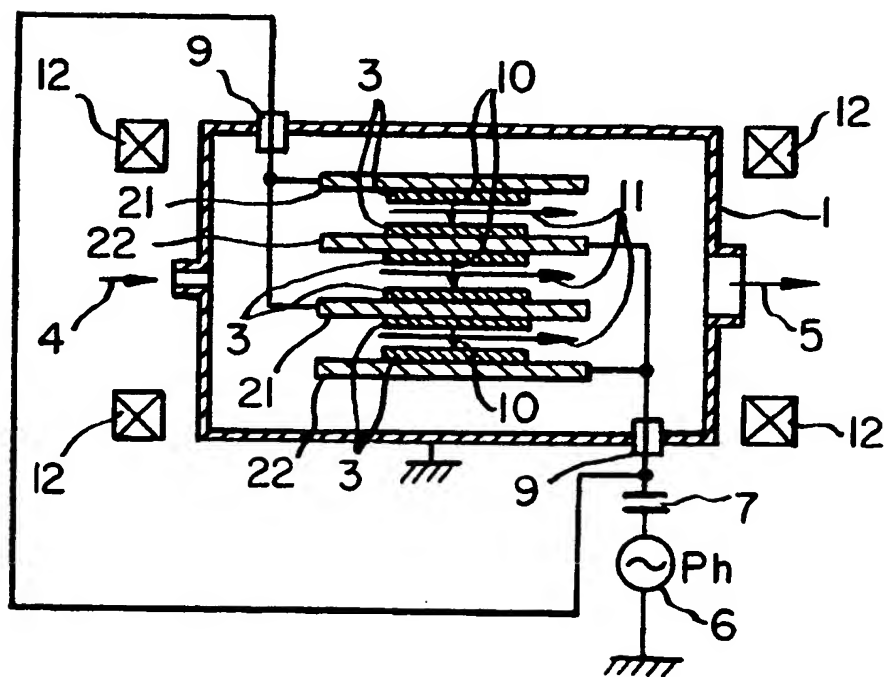


FIG. 5

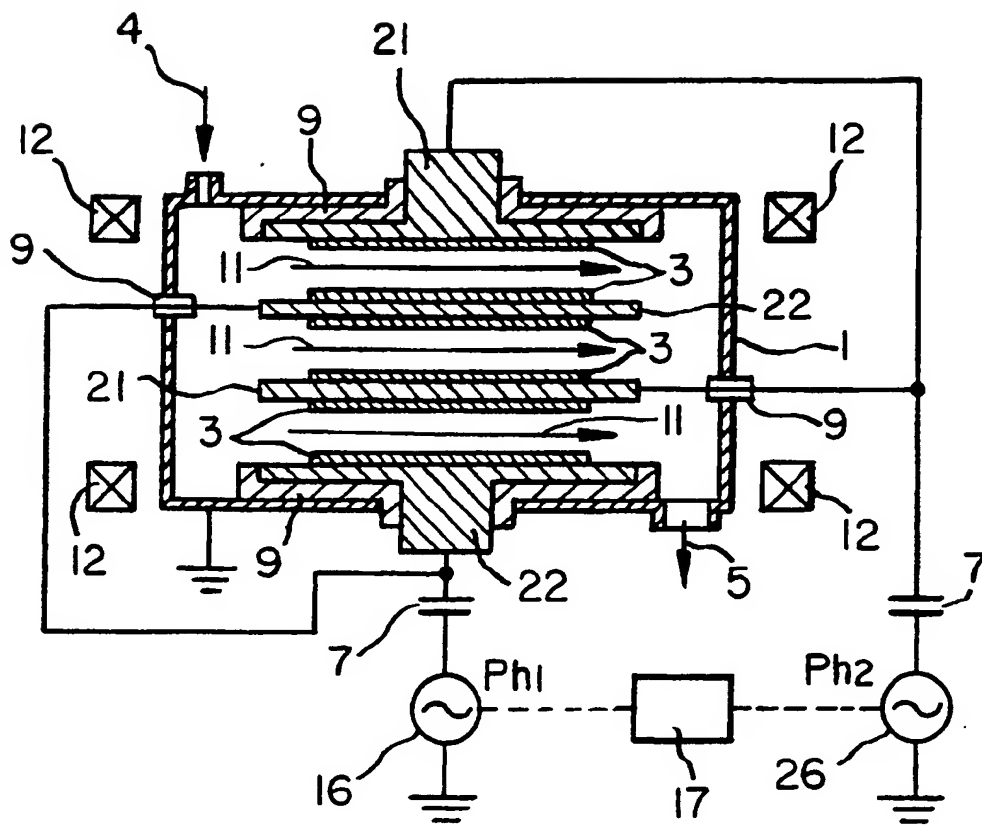
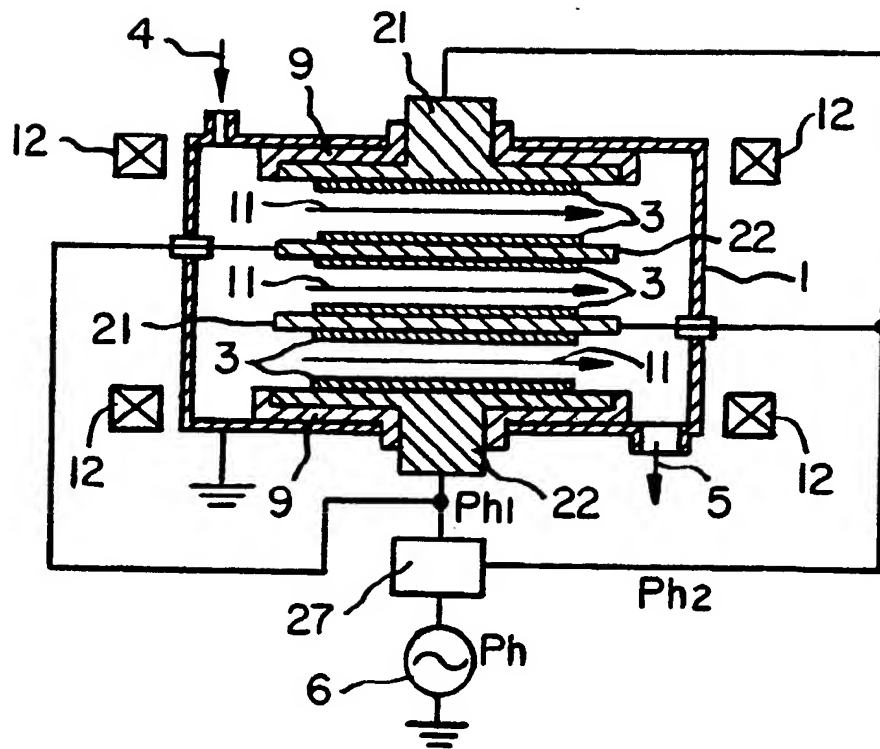


FIG. 6



**FIG. 7**

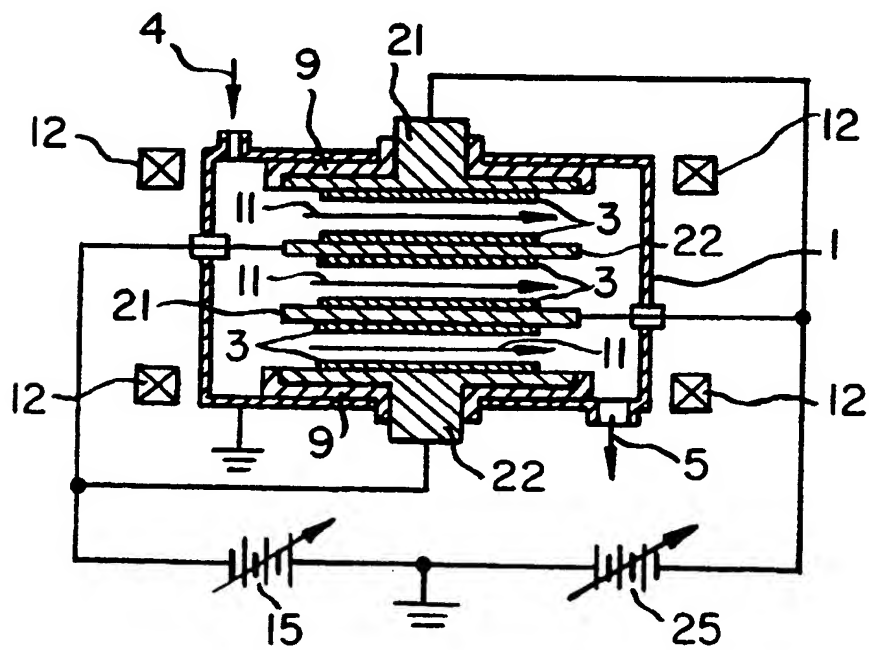


FIG. 8(a)

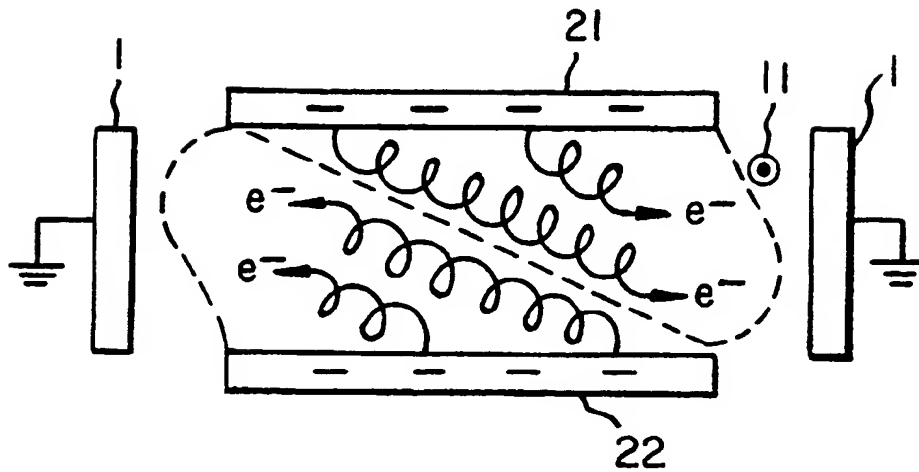


FIG. 8(b)

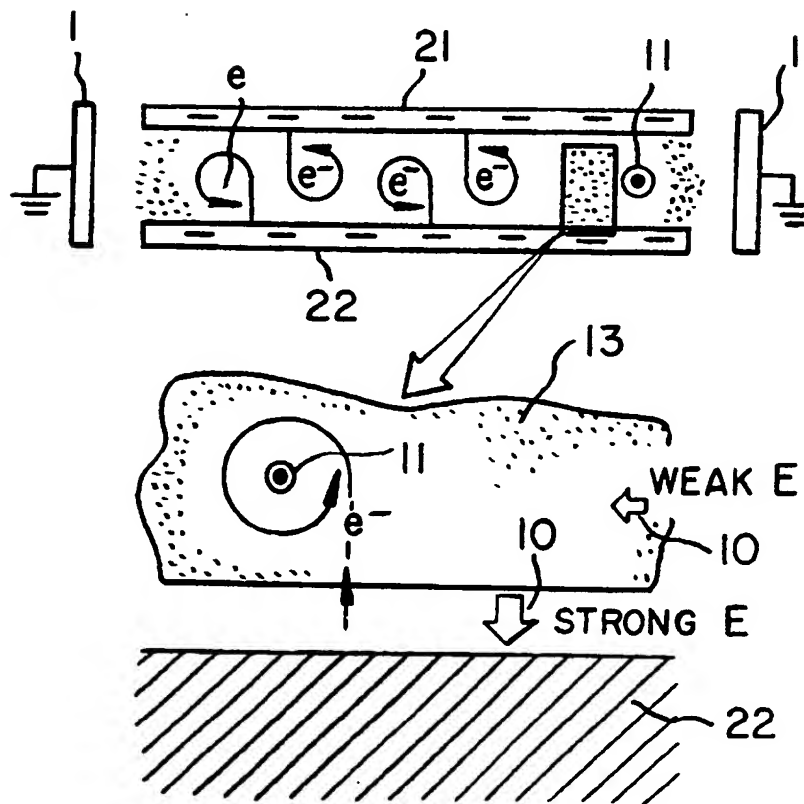


FIG. 9

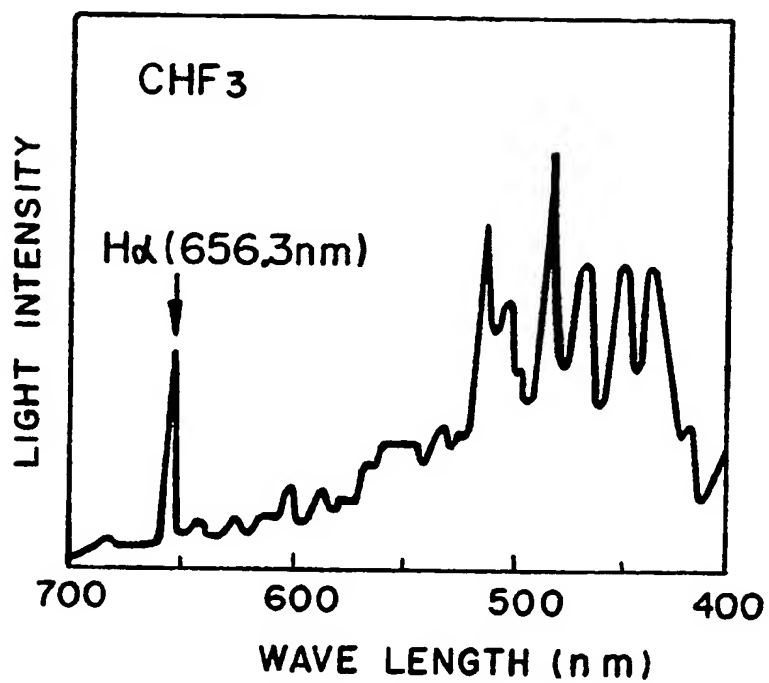


FIG. 10

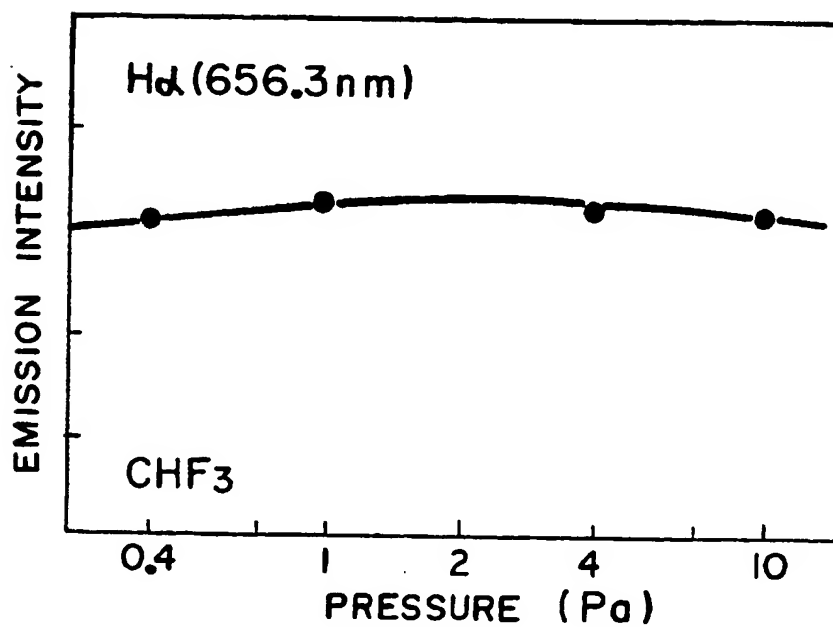


FIG. 11

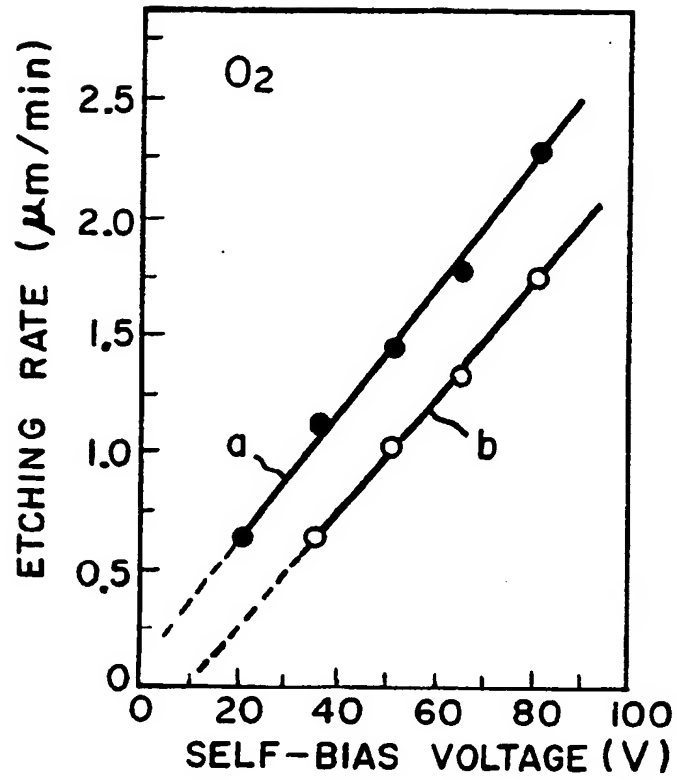
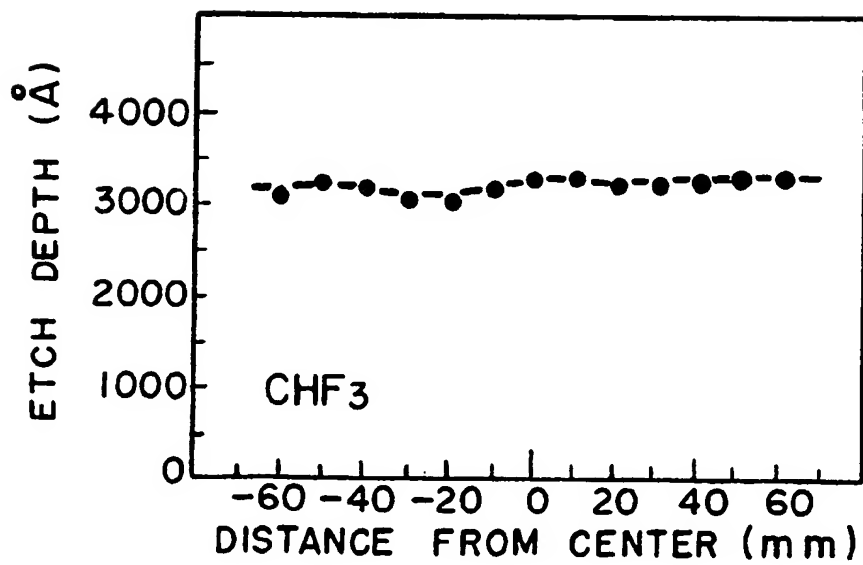


FIG. 12









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**EUROPEAN PATENT APPLICATION**

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**31.07.91 Bulletin 91/31**

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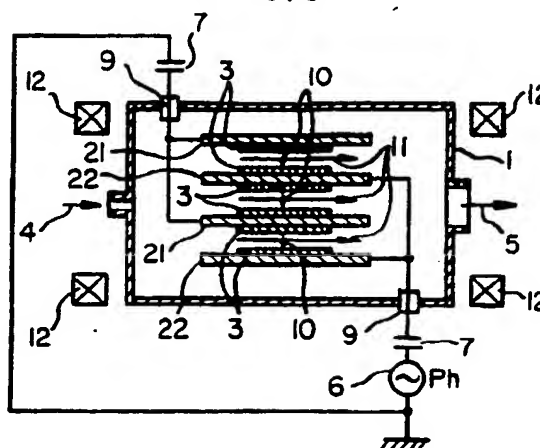
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⑤<sup>4</sup> Dry process system.

57) A dry process system comprises a chamber (1) having an inlet of reaction gas (4) and an exhaust port of exhaust gas (5), more than three electrodes (21, 22) connected with an alternating current power source (6) through a blocking capacitor (7), respectively, and one or plural magnetic field applying means (12) for generating magnetic field nearly parallel to a surface of each electrode. the distance between adjacent electrodes is set to an extent that electrons can travel nearly without collision in the space between adjacent electrodes. Since the distance between adjacent electrodes is narrow, one plasma generated at the neighborhood of one of the adjacent electrode and the other plasma generated at the neighborhood of the other electrode can commingle with each other so that distribution of plasma is made nearly uniform thus nearly uniform plasma can be formed without rotating magnetic field. Since the dry system is provided with electrodes of more than tree pieces, multiple substrates can be effec-

tively processed at the same time.

FIG. 3





European  
Patent Office

## EUROPEAN SEARCH REPORT

Application Number

EP 90 12 1808

### DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
A	GB-A-1 522 059 (STANDARD TELEPHONES AND CABLES LIMITED) * page 1, lines 57 - 80; figure * - - -	1,3,5,12, 15,21	H 01 J 37/34 H 01 J 37/32
A	EP-A-0 172 916 (KANEKAFUCHI KAGAKU KOGYO K.K.) * page 2, lines 12 - 27; figures 2, 3 * * page 3, lines 5 - 29 * - - -	1,3,5,12, 15,21	
A	EP-A-0 140 130 (KANEKAFUCHI KAGAKU KOGYO K.K.) * page 4, lines 23 - 37; figures 5, 6 * * page 5, lines 16 - 18 * - - -	1,5-7,12, 15-17,21	
A	EP-A-0 251 567 (OKI ELECTRIC INDUSTRY COMPANY LTD.) * abstract; figure 11 * * column 3, lines 42 - 57 * - - -	1,12,21	
A	PATENT ABSTRACTS OF JAPAN vol. 8, no. 46 (C-212)(1483) 29 February 1984, & JP-A-58 204174 (HITACHI SEISAKUSHO K.K.) 28 November 1983, * the whole document * - - -	2,4,9,10, 14,18,	
A	US-A-3 325 394 (KAY ET AL.) * column 4, lines 71 - 75; figure 13 * * column 5, lines 32 - 36 * - - - - -	1,12,21	TECHNICAL FIELDS SEARCHED (Int. Cl.5)  H 01 J
The present search report has been drawn up for all claims			

Place of search  The Hague	Date of completion of search  03 June 91	Examiner  COLVIN G.G.
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